NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 390

THE EFFECT OF VALVE TIMING UPON THE PERFORMANCE OF A SUPERCHARGED ENGINE AT ALTITUDE AND AN UNSUPERCHARGED ENGINE AT SEA LEVEL

By OSCAR W. SCHEY and ARNOLD E. BIERMANN

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		km/h	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s^2 $=32.1740$ ft./sec.^{2}

m, Mass $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C. and 750 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 $=0.07651$ lb./ft.^{3}.

mk^2, Moment of inertia (indicate axis of the radius of gyration k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord.

$\frac{b^2}{S}$, Aspect ratio.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$.

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o}=\frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force.

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting (relative to thrust line).

Q, Resultant moment.

Ω, Resultant angular velocity.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;

or for a model of 10 cm chord 40 m/s, the corresponding number is 274,000.

C_p, Center of pressure coefficient (ratio of distance of $c.\ p.$ from leading edge to chord length).

α, Angle of attack.

ϵ, Angle of downwash.

α_o, Angle of attack, infinite aspect ratio.

α_i, Angle of attack, induced.

α_a, Angle of attack, absolute. (Measured from zero lift position.)

γ, Flight path angle.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

(An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. Its membership was increased to 15 by act approved March 2, 1929 (Public, No. 908, 70th Congress). It consists of members who are appointed by the President, all of whom serve as such without compensation.)

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By Oscar W. Schey and Arnold E. Biermann

SUMMARY

This investigation was conducted to determine the comparative effects of valve timing on the performance of an unsupercharged engine at sea level and a supercharged engine at altitude. The tests were conducted by the staff of the National Advisory Committee for Aeronautics on the N. A. C. A. Universal test engine. The timing of the four valve events was varied over a wide range; the engine speeds were varied between 1,050 and 1,500 r. p. m.; the compression ratios were varied between 4.35:1 and 7.35:1. The conditions of exhaust pressure and carburetor pressure of a supercharged engine were simulated for altitudes between 0 and 18,000 feet. The results show that optimum valve timing for a supercharged engine at an altitude of 18,000 feet differs slightly from that for an unsupercharged engine at sea level. A small increase in power is obtained by using the optimum timing for 18,000 feet for altitudes above 5,000 feet. The timing of the intake opening and exhaust closing becomes more critical as the compression ratio is increased.

INTRODUCTION

For the purpose of obtaining information on how the valve timing of a supercharged engine at altitude compares with that of an unsupercharged engine at sea level, the National Advisory Committee for Aeronautics at Langley Field, Va., conducted the tests described in this report.

Of interest in connection with the general problem of valve timing are the tests of Lumet (reference 1), in which the timing of the intake closing event was varied independently of the other events by using a series of different cams. He determined the relation between the timing of the intake valves and the engine performance. Very little information on other tests of this nature is available.

A thorough understanding of the problems connected with valve timing necessitates a study of the pulsating currents of air that traverse the intake and exhaust pipes. The effect of the intake pipe pressure waves on the volumetric efficiency has been determined by Capetti. (Reference 2.) The influence of the exhaust wave phenomena on engine power has been investigated by De Juhasz. (Reference 3.) These two experimenters showed that the effect of pressure waves on the performance of an engine was influenced by many factors of design, as well as by the temperature and pressure of the residue in the cylinder and by the speed of the engine. Although data that are affected by pressure wave phenomena can not then be directly applied to variously designed engines, it is believed that the information presented here will be useful in the study of valve-timing problems in general.

APPARATUS AND METHOD

A photograph of the equipment used in the tests is shown by Figure 1, and a diagrammatic sketch of the general arrangement of the equipment is shown by Figure 2. The latter shows the length of the pipe connections, as well as the volume of the different chambers. The equipment was set up to simulate certain operating conditions for the unsupercharged engine at sea level and for the supercharged engine at altitude. Sea-level pressure was maintained at the carburetor for all runs. The exhaust pressure was reduced to correspond to the conditions at altitude of an engine equipped with a mechanically-driven supercharger. Therefore, all the operating conditions of a supercharged engine were simulated in these tests with the exception of the crankcase pressure and the carburetor air temperature.

The N. A. C. A. single-cylinder Universal test engine equipped with a Stromberg NA–L5 carburetor was used. This engine has a bore of 5 inches and a stroke of 7 inches, and is so constructed that the valve timing, the valve lift, and the compression ratio can be changed while the engine is running. The cylinder head is a pent-roof type of cast iron. It is fitted with two intake and two exhaust valves, having 2¼-inch diameter and 30° seats. Holes are provided in the head for three spark plugs. In these tests two plugs were used, one in the top, centrally located with respect to the four valves, the other in the side, between an intake and an exhaust valve. When an indicator was used, the engine was operated with the central spark plug only. The cams were so constructed that the time of opening and closing of any valve could be changed by varying the dwell of the cam. The valve lift diagram of the intake and the exhaust valves is shown by the curves in Figure 3. A detailed description of this engine may be found in N. A. C. A. Technical Report No. 250. (Reference 4.)

To simulate the conditions of a supercharged engine operating at altitudes above sea level, the exhaust stack was connected to a partly evacuated chamber. The desired degree of evacuation was obtained by varying the quantity of exhaust gas removed from the chamber. In order to prevent injury to the Roots blower, which was used in the removal of the exhaust gases, the gases were cooled by injecting a spray of cold water into the exhaust pipe.

The engine power was absorbed by an electric dynamometer. The torque was measured by a set of calibrated scales, which are standard equipment for this dynamometer. The fuel measurements were obtained by determining the time required to consume 0.50 pound of fuel. A maximum cylinder pressure indicator of the balanced-diaphragm type was used for measuring the compression pressures and a modified Farnboro Indicator (reference 5) was used for recording the pressure variation throughout the cycle. The strength of the indicator spring used in obtaining the high pressure side of the indicator diagrams was approximately thirteen times that for the low pressure side.

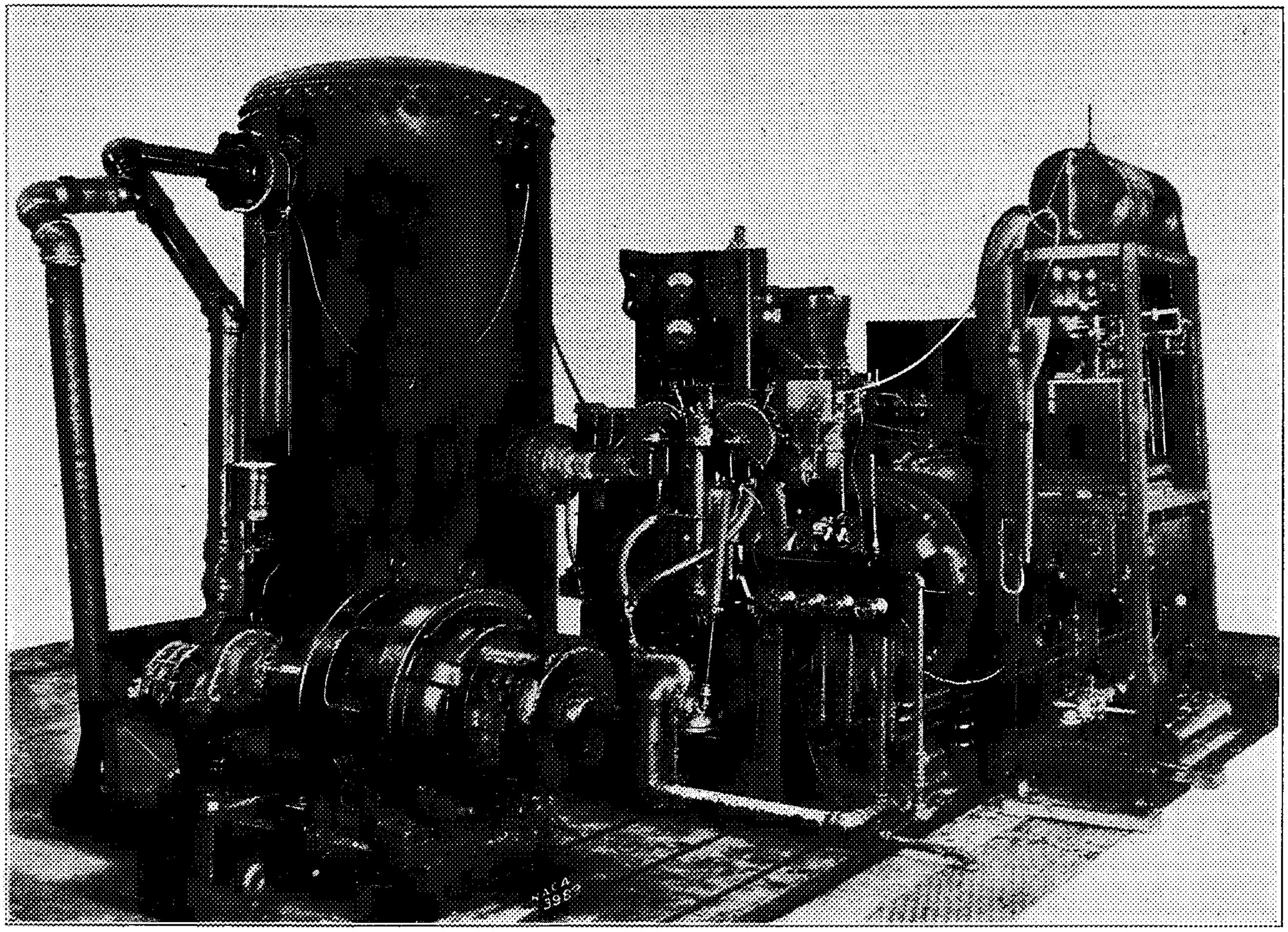

FIGURE 1.—Set-up of laboratory test equipment

All tests were conducted with the throttle full open and with optimum spark setting. Liberty engine oil was used as a lubricant and a mixture of 80 per cent benzol and 20 per cent domestic aviation gasoline, by volume, was used as a fuel. The carburetor was adjusted for maximum power.

The effect of independently varying the intake opening, intake closing, exhaust opening, and exhaust closing on the brake mean effective pressure, the friction mean effective pressure, the fuel consumption, and the compression pressure, was determined for both the supercharged engine at 18,000 feet altitude and for the unsupercharged engine at sea level at engine speeds of 1,200 and 1,500 r. p. m. All compression-pressure data given in this report were obtained during friction runs.

The optimum valve timing was next determined both for the sea-level condition and for an altitude of 18,000 feet, by varying each of the valve events while the engine was operated under power until no further increase in power resulted from the variation of any valve event.

Using the optimum valve timing for the sea-level condition and an engine speed of 1,500, the brake mean effective pressure was determined for altitudes corresponding to 0, 5, 10, and 15 inches of mercury depression (0, 5,000, 10,800, and 18,000 feet altitude). The tests were conducted with the following compression ratios: 4.35, 5.35, 6.35, and 7.35. Similar tests were run with the optimum valve timing for 18,000 feet altitude.

The engine performance was determined, while using the optimum timing for 1,500 r. p. m., when the engine speed was changed to 1,050, 1,200, and 1,350. The valve timing was then changed to obtain maximum power for an engine speed of 1,050, 1,200, and 1,350 at both 0 and 18,000 feet altitude. The performance with each of these valve timings was in turn checked for the three remaining engine speeds.

Assuming that the power varied directly as the pressure and inversely as the square root of the absolute temperature of the carburetor air, all data were corrected to a standard atmospheric pressure of 29.92 inches of mercury and a temperature of 59° F.

RESULTS AND DISCUSSION

The valve timing employed on any particular engine may influence its performance by affecting the weight of the inducted charge, the exhaust opening pressure, and the pumping losses. Other factors of minor importance, such as the compression pressure and the removal of residuals, are also affected, but they are more or less subordinated to the first-mentioned factors.

Pressure wave phenomena.—The length of the intake pipe affects the power chiefly through its effect on the volumetric efficiency; the length of the pipe determines the period of the pressure wave. If it is desired to obtain maximum filling of the engine cylinder, the length of the intake pipe must be increased until a region of compression reaches the cylinder in phase with the valve opening at the time of maximum cylinder volume. For a given engine and pipe length, this optimum condition can only occur when the engine speed bears a fixed relation to the natural frequency of the pipe. By decreasing the pipe length, however, the frequency can be increased until several vibrations occur during one valve opening, and the consequent effect on the mean pressure will be unnoticeable.

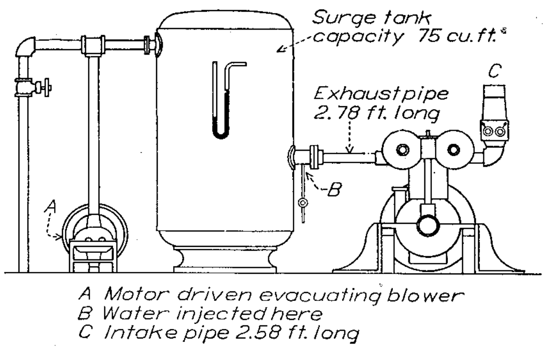

FIGURE 2.—Diagrammatic sketch showing arrangement of laboratory equipment

At the beginning of the test work the length of the intake pipe was 4.1 feet. The effect of the pressure waves was so pronounced that it was impossible to obtain consistent results when either the engine speed or the valve timing was varied. The intake pipe was shortened to the shortest practicable length and the tests were continued without noticeable effect from the pressure waves.

The time of an engine cycle was sufficiently long to allow for the dissipation of the major part of the energy in the pressure waves. Little interference was encountered, therefore, in the following cycle. The pressure waves produced by the initial ejection of the exhaust gases are shown by the indicator cards included in this report. (Figures 8 and 10.)

Independent variation of valve timing.—The effect of varying the time at which the intake valve opens,

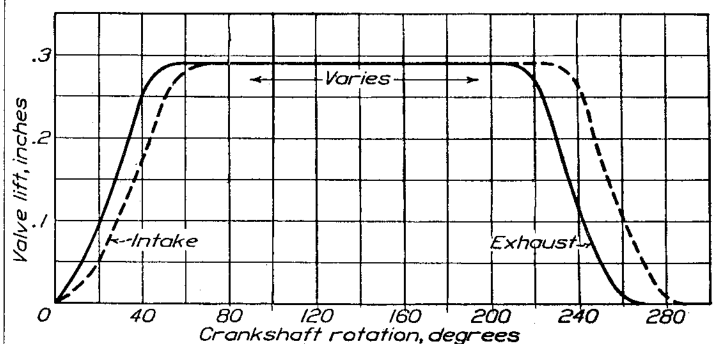

FIGURE 3.—Valve-lift diagram

and using Standard Liberty timing (I. C. 45° after B. C., E. O. 50° before B. C., E. C. 10° after T. C.) for the other valve events is shown in Figure 4. The trend of the power curves for a supercharged engine at 18,000 feet altitude and for an unsupercharged engine at sea level is the same and shows that little, if any, improvement can be gained by using a different time of intake opening for the supercharged engine than that used for the unsupercharged engine. The power curves also show that an earlier opening than that considered standard for a Liberty engine (10° after T. C.) gives more power for the Universal test engine for both conditions.

As the intake valve is opened later, the friction mean effective pressure of a supercharged engine increases more rapidly than that of the unsupercharged engine at sea level, because the supercharged engine is more completely scavenged and, therefore, the pumping losses are greater on the suction stroke. This difference, however, would not exist if the unsupercharged engine were operating at the same altitude as the supercharged with a free exhaust. But, if the supercharged engine had a restricted exhaust (as with the turbosupercharger) and the two engines were operating at the same altitude, the friction conditions would be reversed from those shown in Figure 4.

The effect on the pumping losses of this more complete evacuation of the exhaust is also shown by the indicator cards in Figure 5. These cards show that the decrease in positive work on a supercharged engine with late intake opening (14° after T. C.) as compared with an early opening (34° before T. C.) is greater than the increase in negative work for an unsupercharged engine with the same valve timing.

The increase in engine brake mean effective pressure when supercharging results from two separate effects: One is the reduction in friction mean effective pressure; the other is the increased charge weight. The reduction in friction mean effective pressure is due to the negative pressure within the combustion chamber during the exhaust stroke. The increase in brake mean effective pressure due to reduced friction mean effective pressure for each valve-timing condition may be obtained from friction mean effective pressure curves, and the increase in mean effective pressure due to the combined effect of reduced friction mean effective pressure and increased charge weight may be obtained from the brake mean effective pressure curves.

Figure 6 shows the effect on performance of varying the time of intake closing when the Liberty timing is used for the other valve events. The varying of this event influences all the investigated performance characteristics, except friction. The effect on each characteristic is greater than that obtained by the varying of any other valve event. At the low speeds, the intake valve can be closed earlier than at the

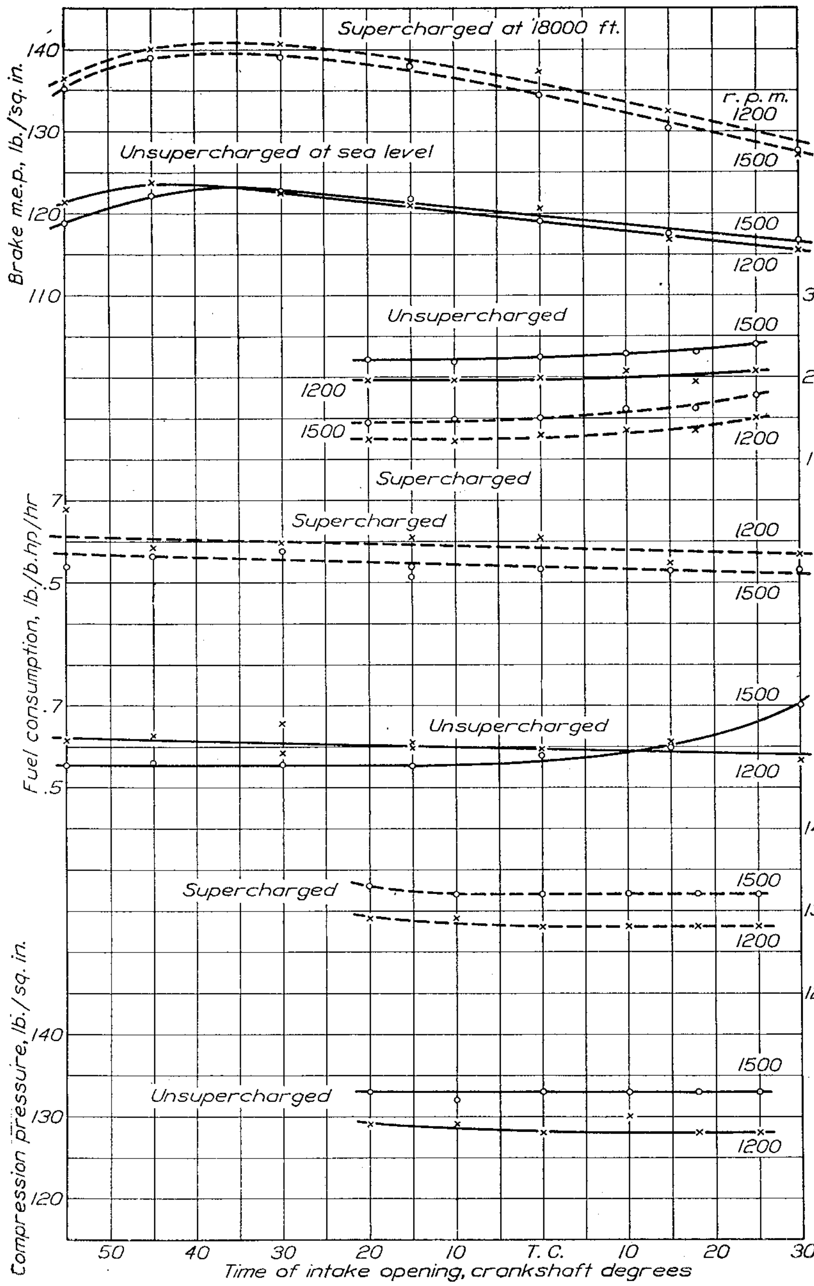

FIGURE 4.—Effect of time of intake opening on performance

higher speeds, because there is sufficient time for the cylinder to fill at some earlier point in the cycle. The tests show that when a late closing is used at low engine speeds, a certain amount of the mixture that is inducted on the suction stroke is forced out on the compression stroke.

Fedden has suggested (reference 6) that an earlier intake closing could be used on a supercharged engine because a late closing would reduce the volumetric efficiency, owing to the pumping back of the mixture through the carburetor. In these tests neither the curves showing the brake mean effective pressure nor the compression curves indicate that there is more pumping back on the supercharged engine with a late timing than on the unsupercharged.

The increase in specific fuel consumption with a late intake closing is caused by: The forcing back through the carburetor of part of the mixture which picks up additional fuel the second time it is inducted; the low compression pressure which results in a low combustion efficiency; the loss of a small amount of fuel which is blown out the intake stack. The increased fuel consumption is greater for an engine speed of 1,200 r. p. m. than it is for a speed of 1,500 r. p. m.

It has been suggested that varying the timing of the intake valve during flight could be used in controlling the weight of air inducted by an overcompressed engine, so that the advantages of high compression ratios might be realized at high altitudes. The compression curves shown in Figure 6 indicate that varying the time of closing of the intake valve is an effective method of controlling compression pressures. The high fuel consumption shown for these tests could be reduced by proper adjustment of the mixture control.

The curves in Figure 7 show the effect on performance of varying the time of exhaust valve opening. From a power standpoint, the results indicate that a slightly earlier exhaust opening is desirable for a supercharged engine at 18,000 feet altitude than that used for an unsupercharged engine at sea level.

The problem in the timing of the exhaust valve is to get rid of the exhaust gases without causing an appreciable pressure on the piston during the scavenging stroke. In these tests the engine power for the supercharged and for the unsupercharged condition decreased with a late exhaust opening. The decrease in power was greater for the higher engine speeds. This decrease in power with a late exhaust opening may be attributed to the additional pressure against which the piston must move on the exhaust stroke. With a late exhaust opening the gases have not sufficient time to escape from the cylinder or to expand to atmospheric pressure before the piston starts on the scavenging stroke. This effect is shown by the indicator cards in Figure 8. A greater weight of charge is inducted by the supercharged engine, and, hence, a greater charge must be exhausted. For this reason, a late exhaust opening is more objectionable on a supercharged engine than on an unsupercharged.

Fedden recommends a late exhaust opening for a supercharged engine; thus, a reduction in valve gear loads is obtained and overheating of the valves is prevented by the lowering of the temperature of the exhaust gases. If it is desirable to use a late exhaust opening to reduce the valve gear loads, cams must be used which are designed to give high valve lift without increasing the acceleration loads. Increasing the diameter of the valves improves the scavenging but in-

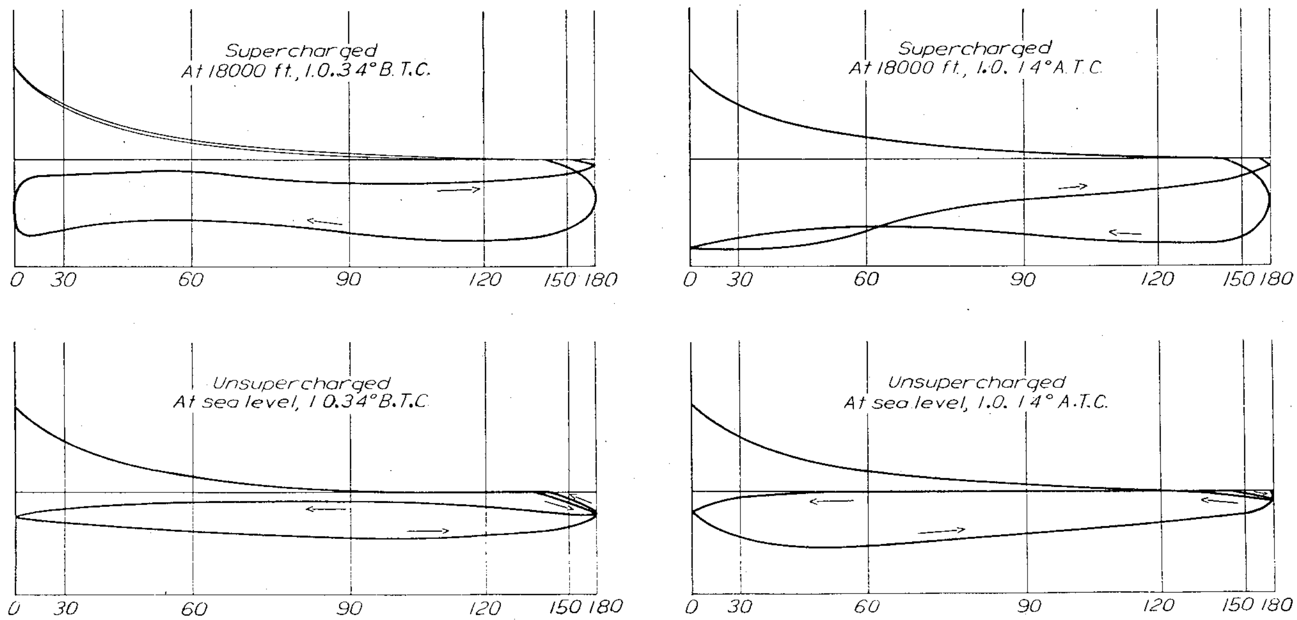

FIGURE 5.—Friction diagrams at 1,500 r.p.m. showing the effect of time of intake opening on pumping losses

creases the valve gear loads and accentuates the difficulty of carrying away the heat from the valves.

In studying the effect of time of exhaust valve opening, as shown by the curves and indicator cards, bear in mind the fact that the unsupercharged engine was operated only at sea level. Had it been operated at a higher altitude, the problem of scavenging with late opening of the exhaust valve would have been easier than it was with the supercharged engine, on account of the lesser weight of charge with the unsupercharged engine.

It is debatable whether the friction horsepower of an engine can be determined by using the dynamometer as a motor to turn the engine. These tests indicate that there may be a large discrepancy between the friction obtained by this method and the friction obtained when the engine is operated under power. With a late exhaust opening when the engine is operating under power, a pressure of 50 pounds per square inch can be obtained at the beginning of the scavenging stroke. With the same valve timing when the engine is driven by the dynamometer, the pressure at the beginning of the stroke is atmospheric. Consequently, the friction curves shown for the variation of the time of exhaust valve opening are not applicable to the case of the engine operating under power.

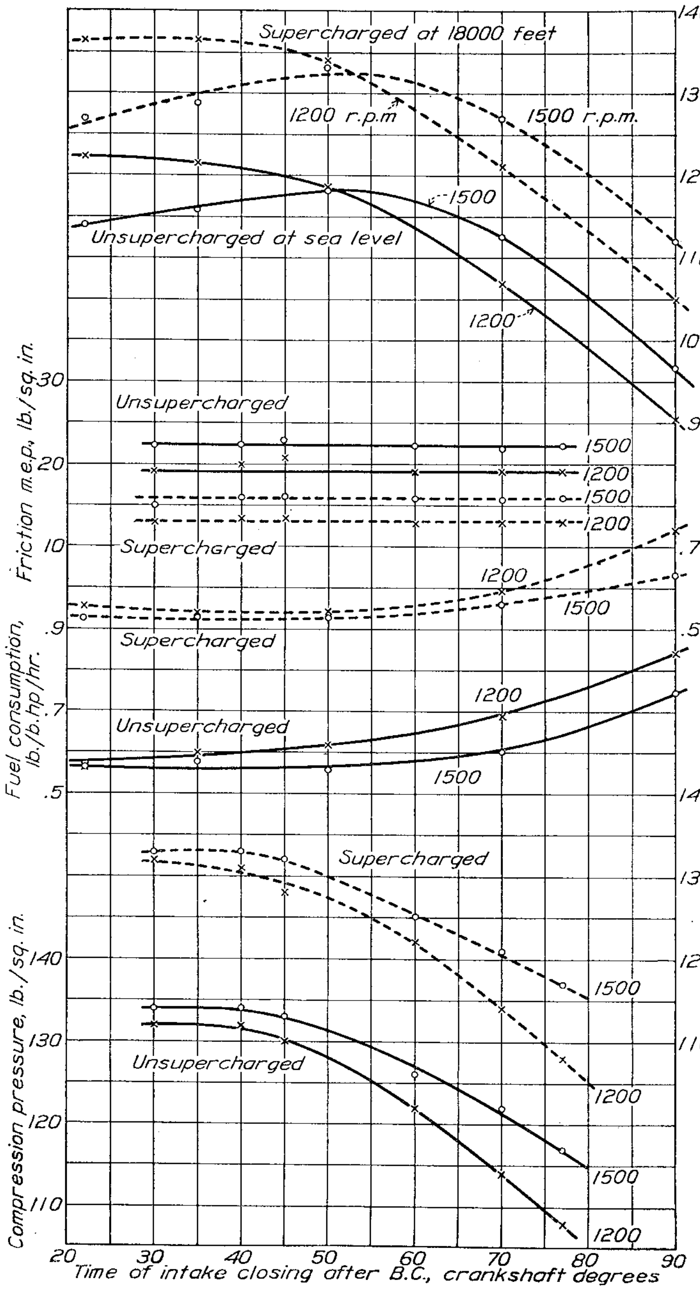

FIGURE 6.—Effect of time of intake closing on performance

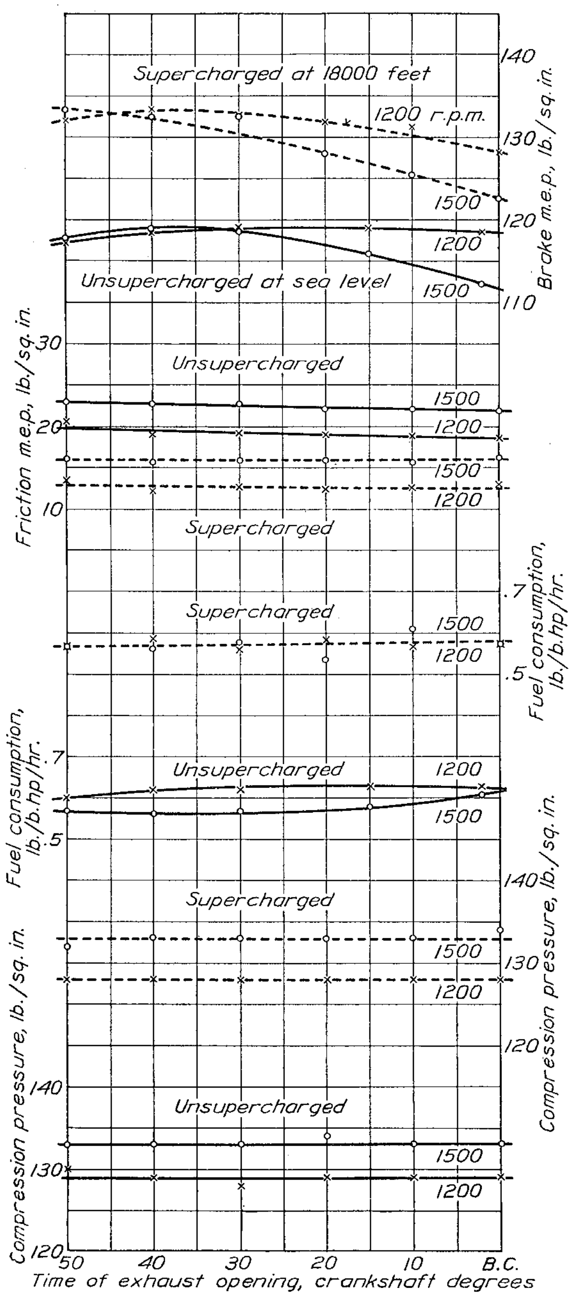

FIGURE 7.—Effect of time of exhaust opening on performance

The curves in Figure 9 show the effect of exhaust-valve closing on the engine performance. From a power standpoint the time of exhaust-valve closing is more critical for the unsupercharged engine at sea level than for the supercharged engine at altitude. This variance in power is caused by the difference in the amount of scavenging obtained for the two conditions. If the exhaust valve closes early on the unsupercharged engine at sea level, a quantity of the exhaust gases will be trapped in the combustion chamber. If it closes late the gases that have been exhausted may be drawn back into the chamber when the piston starts on the intake stroke. The indicator cards in Figure 10 show the effect of time of exhaust valve closing on the pressures at the end of the scavenging stroke for a supercharged and an unsupercharged engine.

The other performance characteristics of a supercharged and an unsupercharged engine, such as friction, fuel consumption, and compression pressure, are influenced very little by the time of exhaust-valve closing.

Optimum valve timing as affected by compression ratio.—Thus far we have considered only the effect of varying independently each valve event. The performance obtained with the optimum valve timing must also be considered. Figure 11 shows a comparison of the power developed at different altitudes, using the best valve setting for the unsupercharged engine at sea level and the best setting for the supercharged engine at 18,000 feet for the four compression ratios. These curves indicate that slightly better performance over a greater range of altitude can be obtained with the optimum valve timing for the supercharged engine at 18,000 feet altitude than can be obtained with the optimum timing for the unsupercharged engine at sea level. The higher the compression ratio the more the engine power is affected by

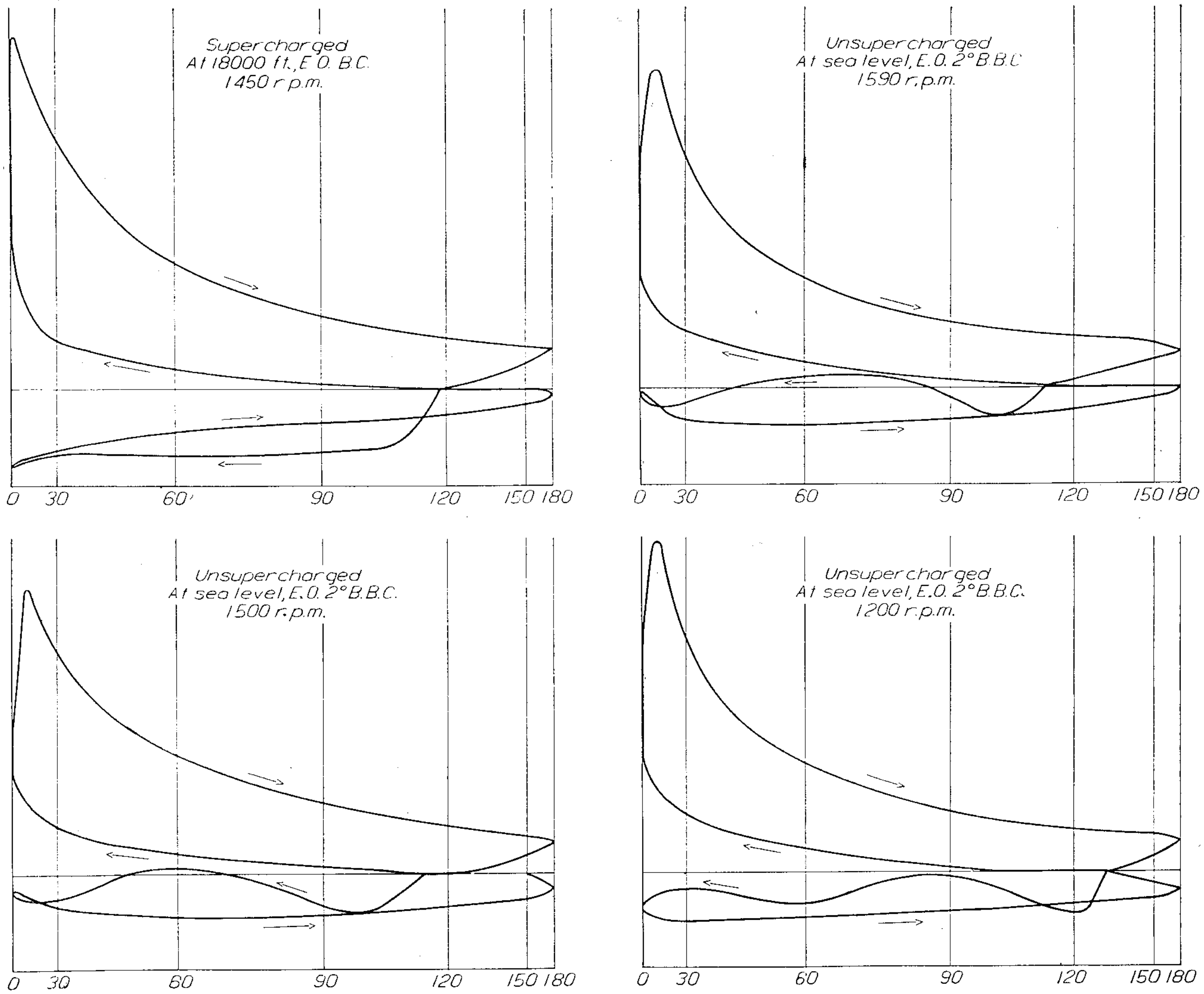

FIGURE 8.—Indicator diagrams showing the effect at different speeds of late exhaust opening on the pressure during the exhaust stroke

small changes in valve timing. However, in no case for the altitudes from 0 to 18,000 feet is there more than a 5 per cent difference between the values of the power obtained.

Optimum valve timing as affected by engine speed.—Figure 12 presents information on the optimum valve

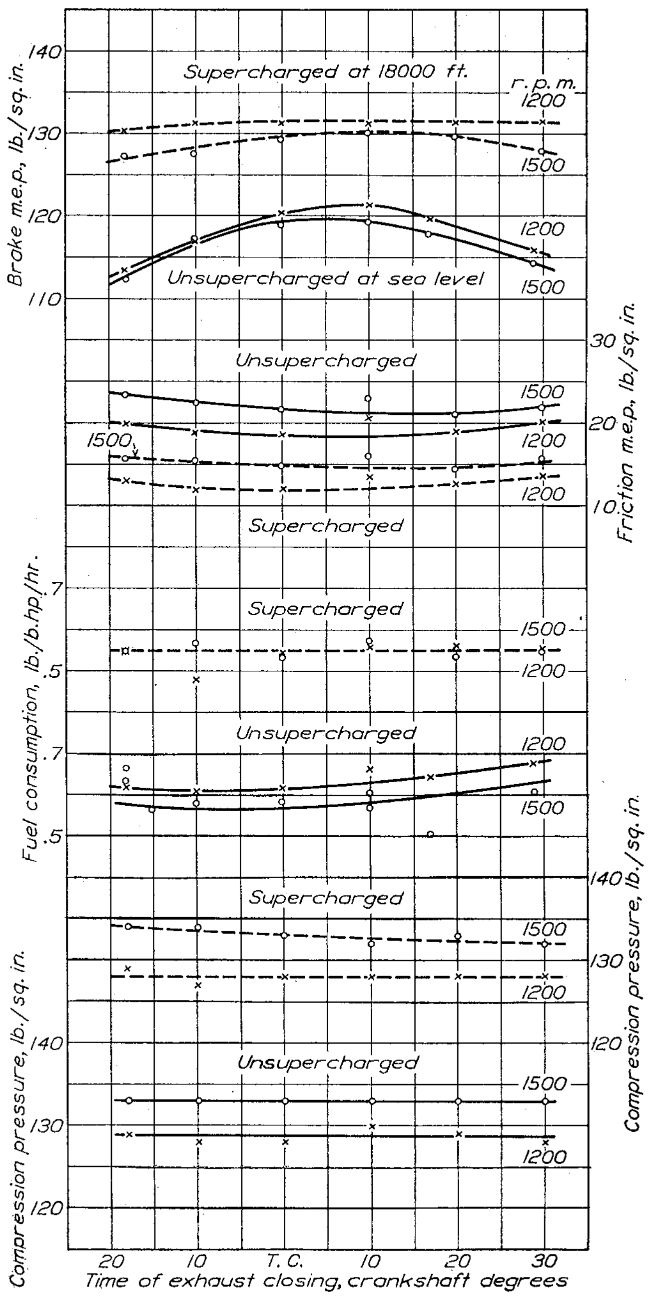

FIGURE 9.—Effect of time of exhaust closing on performance

timing for different engine speeds. The curves in groups E, F, G, and H represent the best timing at speeds from 1,050 r.p.m. to 1,500 r.p.m. for the supercharged and unsupercharged engine. The brake mean effective pressure obtained while using the optimum timing determined for one speed and operating at engine speeds from 1,050 to 1,500 r.p.m. is shown by the curves in groups A, B, C, and D. These curves show that the valve timing that is best for the high speeds will also give good performance at the low speeds, but the valve timing that is best for the low speeds will not be so satisfactory for the high speeds. Although these valve timings are the best for the speed and other given conditions, it must be remembered that for some events it took a large variation in timing to effect even a small change in power, and that at no time did the optimum timing for one speed give a reduction in power of more than 7 per cent at any other speed. The maximum reduction in power was obtained at a speed of 1,500 r.p.m. when operating with the optimum valve timing for a speed of 1,050 r.p.m. Operating with the optimum timing for a speed of 1,500 r.p.m. resulted in a reduction in power of less than 3 per cent when operating at any speed from 1,050 to 1,500 r.p.m.

CONCLUSIONS

The information in this report is not conducive to definite conclusions regarding the best valve timing to use for different types of engines under various operating conditions. The test results submitted do form a guide for the selection of the valve timing for other engines operating under conditions similar to those of the test.

The results of these tests indicate that:

1. The optimum timing for the supercharged engine at an altitude of 18,000 feet differs slightly from that for the unsupercharged engine at sea level. Its use at altitudes above 5,000 feet results in a small increase in power.
2. The power of a supercharged engine operating at altitude with a free exhaust is less affected by changes in valve timing than the power of the unsupercharged engine at sea level.
3. The optimum valve timing for both the unsupercharged engine at sea level and the supercharged engine at altitude changes slightly with compression ratio. Timing of the valve events occurring at the top of the stroke, intake opening, and exhaust closing, becomes more critical with increase in the compression ratio.
4. The optimum valve timing for an engine speed of 1,500 r.p.m. gives less reduction in brake mean effective pressure at lower engine speeds than does the optimum timing for the low speeds when used at 1,500 r.p.m.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *February 4, 1931.*

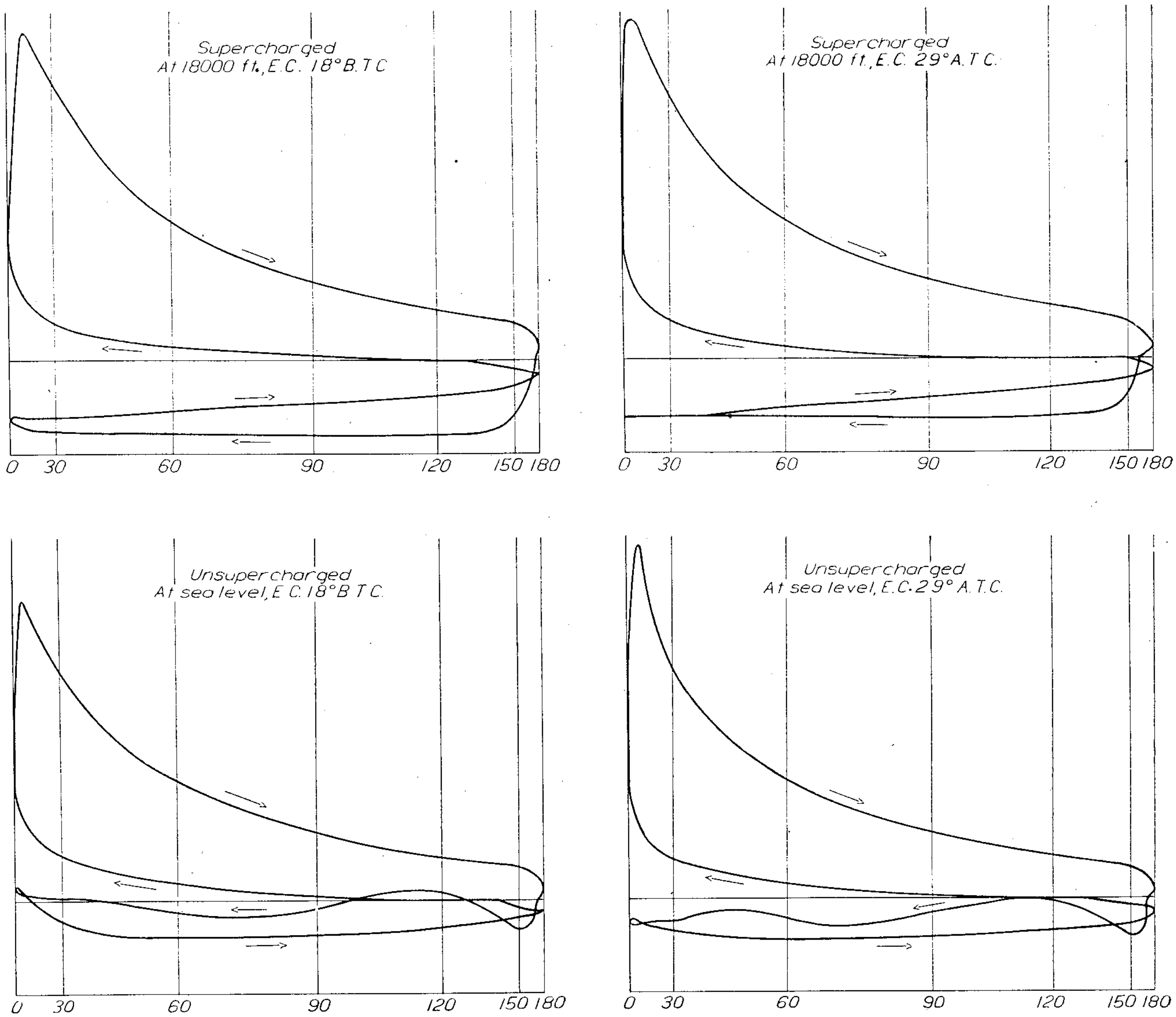

FIGURE 10.—Indicator diagrams showing the effect of the time of exhaust valve closing on pressures at end of scavenging stroke with an engine speed of 1,500 r. p. m.

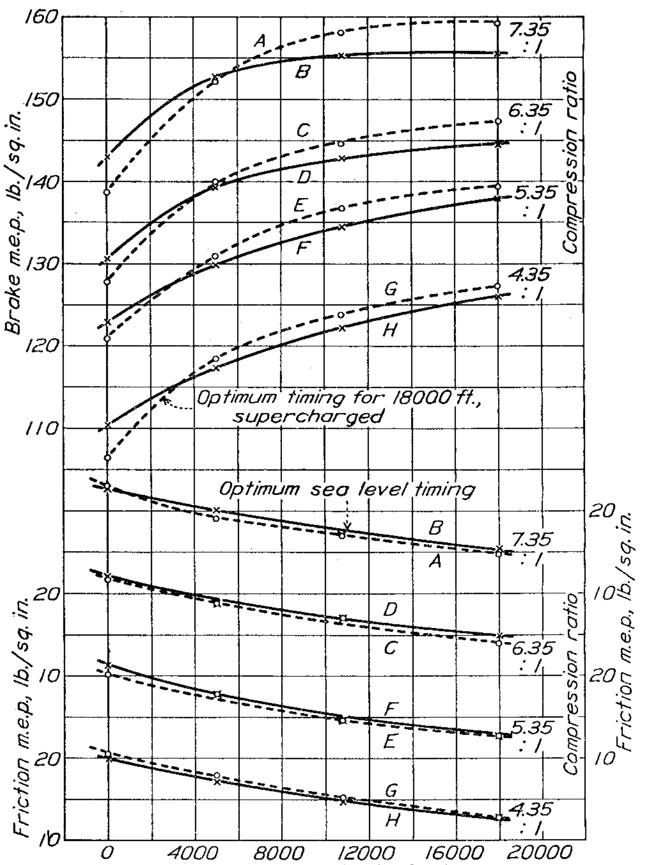

FIGURE 11.—B. m. e. p. and f. m. e. p. at 1,500 r. p. m. with optimum timing for both the unsupercharged engine at sea level and the supercharged engine at 18,000 feet altitude

Curve	Valve timing			
	I. O.	I. C.	E. O.	E. C.
	°B. T. C.	°A. B. C.	°B. B. C.	°A. T. C.
A	23	43	33	13
B	23	43	48	25
C	20	41	29	17
D	24	40	41	23
E	22	40	24	24
F	18	43	41	29
G	18	35	39	28
H	43	48	47	15

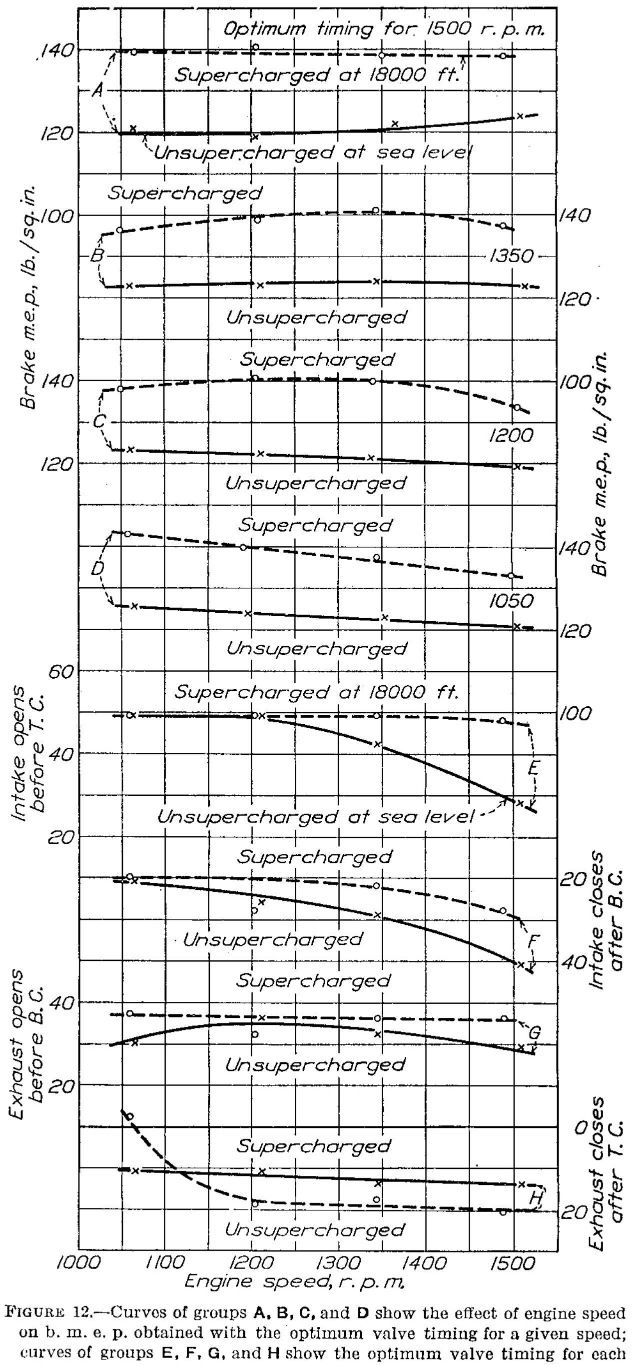

FIGURE 12.—Curves of groups **A, B, C,** and **D** show the effect of engine speed on b. m. e. p. obtained with the optimum valve timing for a given speed; curves of groups **E, F, G,** and **H** show the optimum valve timing for each speed

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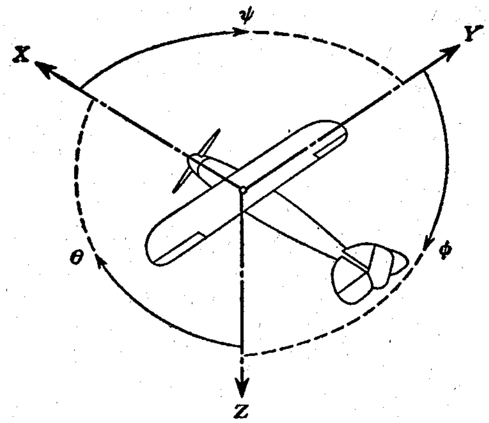

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	ϕ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	ψ	w	r

Absolute coefficients of moment

$$C_l=\frac{L}{qbS} \qquad C_m=\frac{M}{qcS} \qquad C_n=\frac{N}{qbS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p, Geometric pitch.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slipstream velocity.
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2D^5}$

P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3D^5}$.
C_s, Speed power coefficient $=\sqrt[5]{\frac{\rho V^5}{Pn^2}}$.
η, Efficiency.
n, Revolutions per second, r. p. s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.